High Efficiency Low Noise SMPS System
- DC-DC Converter Side -

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Abstract - **Improvement of DC-DC converter side in SMPS system is discussed in this paper. A novel forward type soft switching DC-DC converter topology with neutral point inductor connected Auxiliary resonant snubber (NPC-ARS) circuit is presented in this paper for the switching mode power supply applications. Its circuit operation and its performance characteristics of the forward type soft switching DC-DC converter is described and discussed on the bases of experimental results.**

Keywords ; **Forward type DC-DC converter, Zero voltage soft switching, Zero current soft switching, neutral point inductor connected Auxiliary resonant snubber (NPC-ARS) circuit**

I. INTRODUCTION

In recent years, the switching mode power supply (SMPS) system have been achieved the high power density and high performances by developed power semiconductor devices such as; IGBT, MOS-FET and SiC. However, using the switching power semiconductor in the SMPS system, the problem of the switching loss and EMI/RFI noises have been closed up. This course produced the EMC limitation like the International Special Committee on Radio Interference (CISPR) and the harmonics limitation like the International Electrotechnical Commission (IEC). For keeping up with the limitation, the SMPS system must add its system to the noise filter and the metal and magnetic component shield for the EMI/RFI noises and to the PFC converter circuit and the large input filter for the input harmonic current. On the other hand, the power semiconductor device technology development can achieve the high frequency switching operation in the SMPS system. The increase of the switching losses have been occurred by this high frequency switching operation. Of course, the inductor and transformer size have been reduced by the high frequency switching, while the size of cooling fan could be

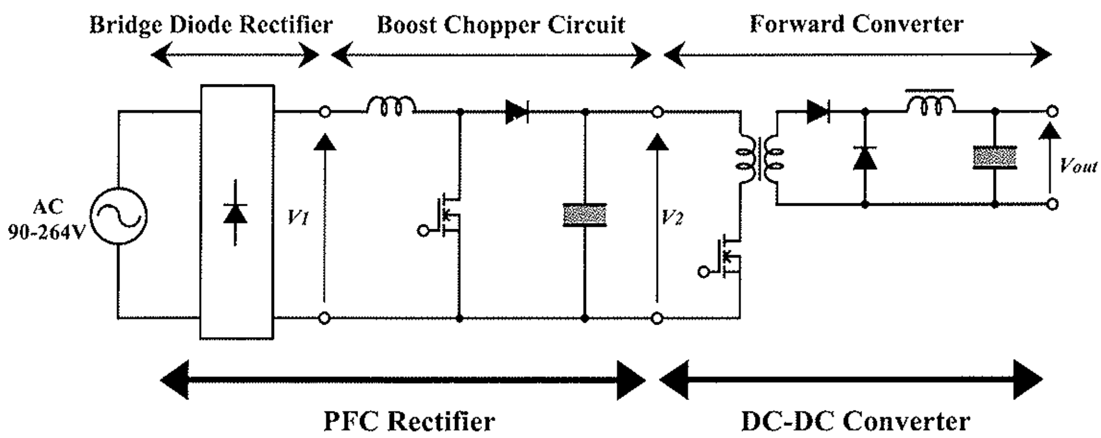


Fig.1. SMPS system configuration of research target.

huge because of the increase of the switching losses.

Our research target is to reduce the EMI/RFI noises and the switching losses in the SMPS system by only one method. The solution method is the soft switching technique. Using LC resonant phenomenon, this technique can minimize the switching power losses of the power semiconductor devices, and reduce their electrical dynamic and peak stresses, voltage and current surge-related EMI/RFI noises under high frequency switching strategy.

Thus, a new conceptual circuit configuration of the advanced forward type soft switching DC-DC converter which has the neutral point inductor connected auxiliary resonant snubber (NPC-ARS) circuit is presented in this paper with its operating principle in steady state. In addition, its fundamental operation and its performance characteristics of the proposed forward type soft switching DC-DC converter treated here are evaluated on the basis of experimental results.

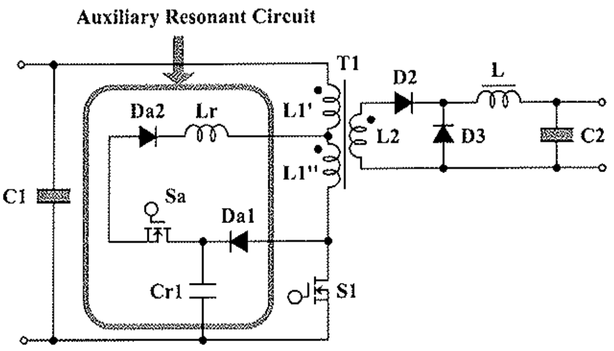


Fig.2. Forward type soft switching DC-DC converter with a neutral point inductor connected auxiliary resonant snubber (NPC-ARS) circuit.

II. Novel Forward Type Soft Switching DC-DC Converter

The typical switching mode power supply circuit configuration of our research target is shown in Fig.1. We have modified the part of DC-DC converter to achieve the complete soft switching operation in active power semiconductor devices of the forward converter. Fig.2 shows the schematic configuration of the modified forward type soft switching DC-DC converter with a neutral point inductor connected auxiliary resonant snubber (NPC-ARS) circuit. The proposed NPC-ARS circuit consist of an active power semiconductor devices; Sa, a resonant capacitor Cr1, two power diode Da1 and Da2. Using this NPC-ARS circuit, the zero voltage soft switching (ZVS) turn off or the zero current soft switching (ZCS) turn on can be achieved in main switching device S1, and ZCS turn on and turn off be in auxiliary switch Sa. So that, the switching losses in each active power semiconductor device will be zero completely.

III. Operation Principle of NPC-ARS Circuit

The operation principle of the proposed forward type soft switching DC-DC converter with the NPC-ARS circuit is illustrated in Fig.3. The conventional forward type DC-DC converter operates only two circuit condition mode which is described in Fig.3 as the steady state mode on and off. On the other hand, there is 4 mode in case of the proposed one as depicted in Fig.3. The illustration waveforms on each 4 mode in case of the proposed one is described in Fig.4. The operating principle of the proposed forward type soft switching DC-DC converter is described as follows;

[Steady State Mode ON]; In this state, the transformer current flows through the main active power semiconductor device S1 and the primary energy conducts to secondary side of transformer. If the main active power semiconductor device S1 is turned off, the operation mode changes to the next circuit condition mode, Commutation Mode 1.

[Commutation Mode 1]; The energy in the leakage inductance of transformer T1 is flowing through the resonant capacitor Cr1 by turned main active power semiconductor device S1 off. When the leakage inductance current reach zero, the operation mode changes to the next steady state mode, Steady State Mode OFF.

[Steady State Mode OFF]; The energy in the primary side of transformer is broken off the secondary side in this circuit condition mode. If the main active power semiconductor device S1 and auxiliary active power semiconductor device Sa are turned on, the operation mode changes to the next circuit condition mode, Commutation Mode 2.

[Commutation Mode 2]; In this mode, the active power semiconductor devices S1 and Sa can be achieved the complete ZCS transition by the leakage inductance and auxiliary resonant inductor Lr. The energy in the primary side of transformer T1 is conducted to the secondary side. Furthermore, the energy in the resonant capacitor Cr1 flow to the secondary side of the transformer through the transformer T1. When the voltage of the resonant capacitor Cr1 reaches zero, the operation mode is changed to the first circuit condition mode, Steady State Mode ON.

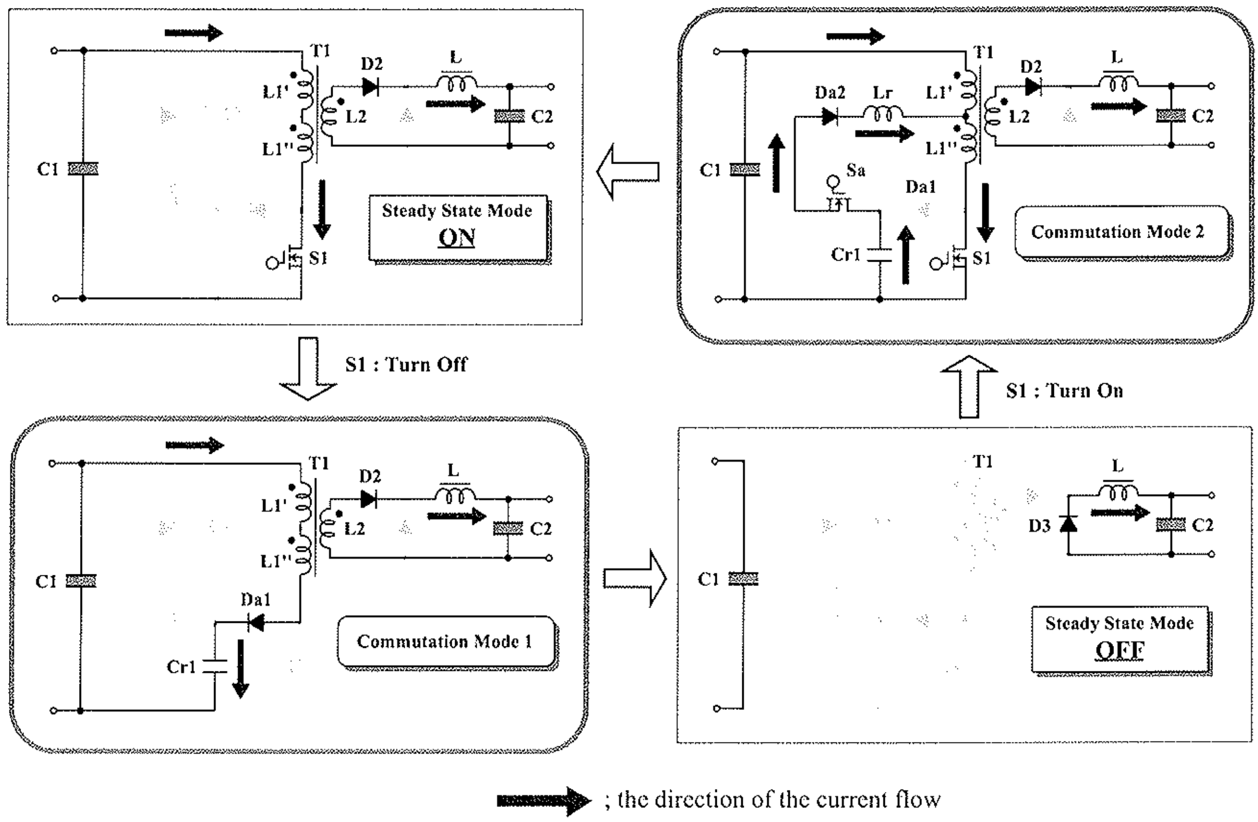


Fig.3. Eqivalent circuit for each operation stage of the proposed forward type soft switching DC-DC converter with the NPC-ARS circuit.

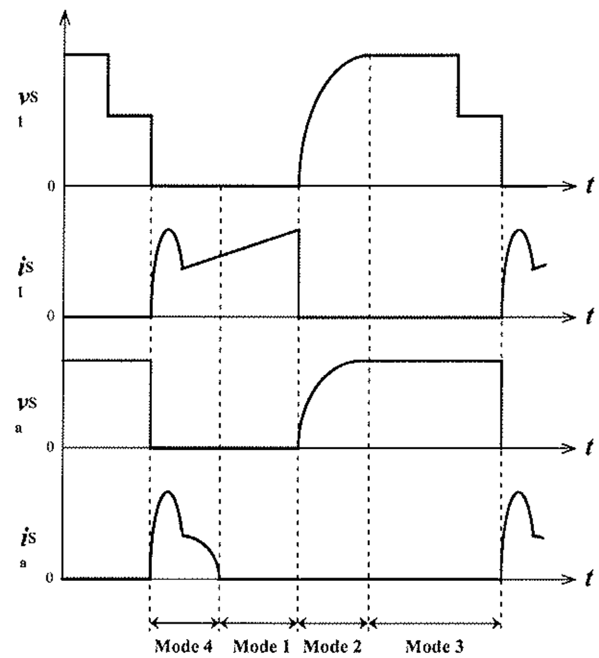


Fig.4. Illustration waveforms on Each mode in case of the proposed forward type soft switching DC-DC converter with the NPC-ARS circuit.

IV. Experimental Setup

The equivalent circuit of conventional forward type DC-DC converter is illustrated in Fig.5 for the feasible evaluation of the comparative data between the conventional one and the proposed one. In the conventional type, the main power transformer T1 is composed of the ferrite core (PC40EER40;TDK) and 3 windings L1', L1" and L2. Its windings ratio is follows as; L1':L1":L2=1:1:2. On the other hand, the main power transformer consists of the ferrite core (PC40EER40;TDK) and 3 windings L1', L1" and L2, too. However, its windings ratio, which is different from the conventional one, is follows as; L1':L1":L2=1:5:6. Furthermore, the auxiliary resonant inductor Lr is composed of the ferrite core (PC40EER28;TDK) and 10 windings. The other important circuit parameters are indicated in TABLE I in the conventional type. The circuit parameters in the proposed one are in TABLE II. This experimental setup substitution the input DC voltage for the regulated DC power supply, and the output load for the constant resistance.

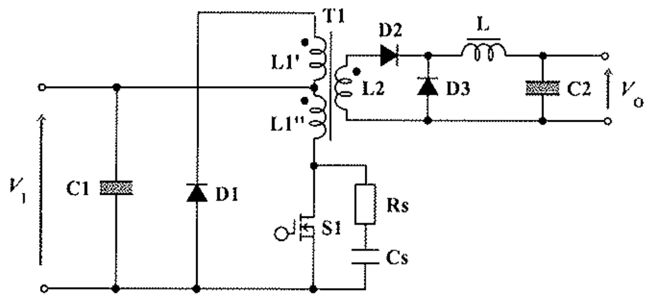


Fig.5. Equivalent circuit of conventional forward type DC-DC converter.

TABLE I
CIRCUIT PARAMETERS OF CONVENTIONAL CIRCUIT

Parameter	Unit	Value and Items
Input Voltage; V_I	[V]	100
Output Voltage; V_O	[V]	42
Output Power; P_O	[W]	120
Switching Frequency; f_S	[kHz]	100
Smoothing Capacitor, C1, C2	[μF]	470
Output Smoothing Inductor; L	[μH]	510
Capacitance of Snubber Circuit; Cs	[pF]	100
Resistance of Snubber Circuit; Rs	[Ω]	47
Power MOS-FET (S_1, S_a)		IRFBC40
Power Diode (D_1, D_2, D_3)		HFA08TB60

TABLE II
CIRCUIT PARAMETERS OF PROPOWED CIRCUIT

Parameter	Unit	Value and Items
Input Voltage; V_I	[V]	100
Output Voltage; V_O	[V]	42
Output Power; P_O	[W]	120
Switching Frequency; f_S	[kHz]	100
Smoothing Capacitor, C1, C2	[μF]	470
Output Smoothing Inductor; L	[μH]	510
Inductance of NPC-ARS circuit; Lr	[μH]	10
Capacitance of NPC-ARS circuit; Cr1	[nF]	100
Power MOS-FET (S1, Sa)		IRFBC40
Power Diode (Da1, Da2, D2, D3)		HFA08TB60

V. EXPERIMENTAL RESULTS

The experimental tests have been carried out on two systems which circuit parameters are reported in Table I and Table II. In this section, waveforms obtained from the forward type soft switching DC-DC converter with NPC-ARS circuit will be compared to the one from the conventional forward type DC-DC converter.

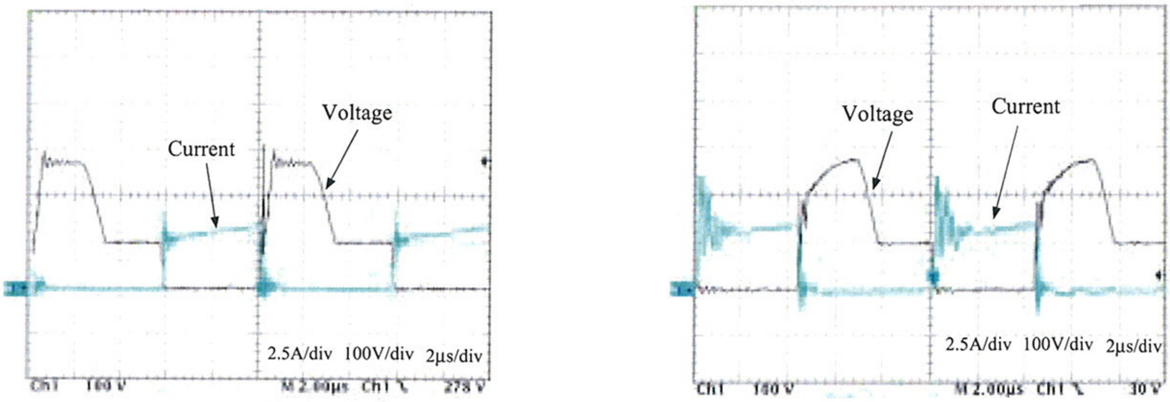
Fig.6 shows comparative voltage and current operating waveforms of the power MOS-FET S1 in case of the conventional forward type DC-DC converter and the proposed forward type soft switching DC-DC converter. In spite of additional the NPC-ARS circuit, it is understood that the proposed type can achieve the standard operation of the forward converter. The comparative voltage and current waveforms at turn off operation across the power MOS-FET S1 are indicated in Fig.7. In case of the conventional type, the voltage and current waveforms respectively cross over. On the other hand, in case of the proposed type, the voltage and current waveforms can not cross over at all. This means that a perfect soft switching commutation has been achieved, and the switching losses are effectively reduced. And from this figure, the voltage waveform of the power MOS-FET S1 in soft switching have a slow sloop, so it is expectable that EMI noises could be reduced.

The obtained voltage and current waveforms from the power MOS-FET Sa which is the part of NPC-ARS circuit is shown in Fig.8. It is confirmed that the zero current soft switching commutation have been achieved in the power MOS-FET Sa, too.

The comparative power efficiency between the conventional type and the proposed type are shown in Fig.9. In lower output power condition, the efficiency in the proposed type is less than the conventional type, because the current through the NPC-ARS circuit is larger than the current through main forward converter circuit. However, the efficiency in the proposed type have been taken over in the higher output power condition. This means that the switching losses are remarkable in the higher output power condition, because the current through the main forward converter circuit increase as compared with the current through the NPC-ARS circuit.

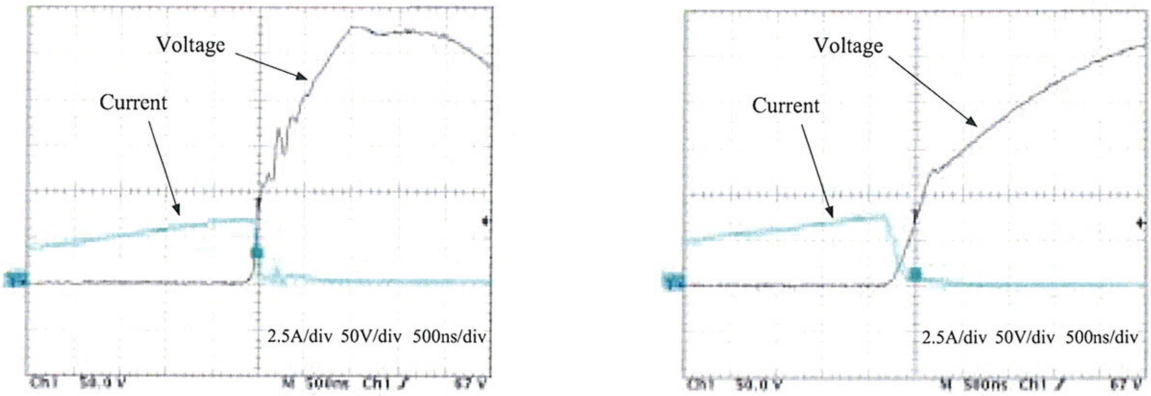
VI. CONCLUSIONS

A new conceptual circuit configuration of the forward type soft switching DC-DC converter which has a neutral point inductor connected auxiliary resonant snubber (NPC-ARS) cir-



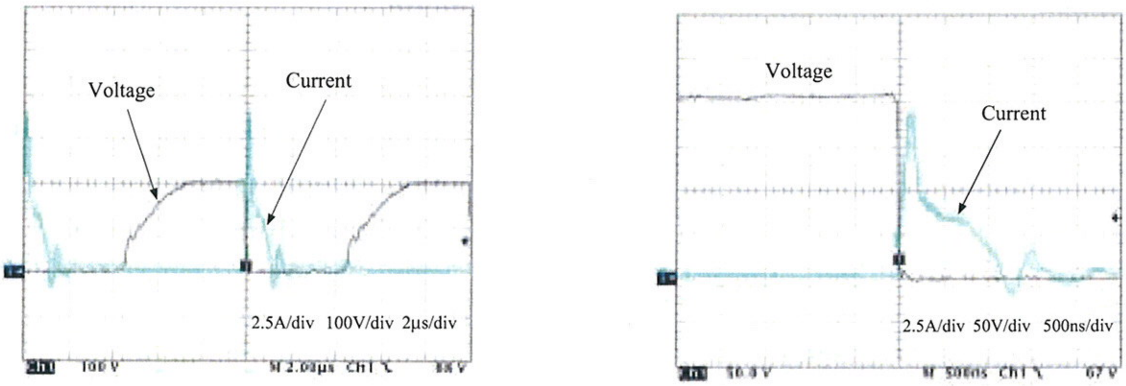
(a) (b)

Fig.6. Comparative voltage and current waveforms across power MOS-FET S1: (a) Conventional type and (b) Proposed type.



(a) (b)

Fig.7. Comparative turn off voltage and current waveforms across power MOS-FET S1: (a) Conventional type and (b) Proposed type.



(a) (b)

Fig.8. Voltage and current waveforms across power MOS-FET Sa: (a) Overview and (b) Details.

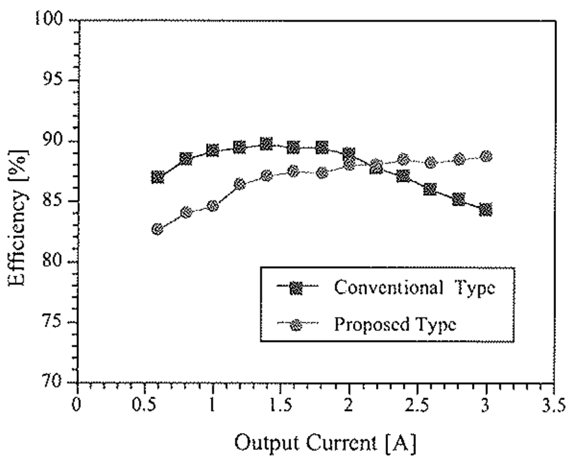


Fig.9. Comparative power efficiency between the conventional type and proposed type.

cuit is presented with its operating principle in steady state in this paper. In addition, its operating performances of the proposed forward type soft switching DC-DC converter developed by the authors are evaluated and discussed on the basis of experimental results. From these results, it is confirmed that the soft switching commutation have been achieved in case of both the MOS-FET S1 and Sa. Furthermore, the efficiency is improved in higher output power condition. So the proposed forward type soft switching DC-DC converter is suitable for high power applications.

Of couse, there are some problem to adding the NPC-ARS circuit. First, the proposed forward type converter need another isolated power supply for the additional MOS-FET Sa. Second, because of the addition of NPC-ARS circuit for complete soft switching commutation, the scale of the proposed type converter will be larger than the conventional type one. However, considering the each circuit parameter such as Lr and Cr1, the losses of NPC-ARS circuit will be decreased. Furthermore, the scale of cooling system will be reduced by the optimum design, too, because the losses in each MOS-FET is reduced remarkably.

In the future, the total performance of the SMPS system which include the single phase PFC rectifier side must be evaluated and discussed from a practical point of view.

References

[1] Gerry Moschopoulos and Geza Joos, "A Novel Soft-Switched PWM Current Source Rectifier/Inverter", Proc. of 25th IEEE Annual Power Electronics Specialists Conference, pp.978-984, 1994

[2] R.W.De Doncker "The Auxiliary Resonant Commutated Pole Converter", IEEE IAS '89 Records, pp.829-834, 1989

[3] W.MacMarray "Resonant Snubbers With Auxiliary Switches", IEEE-IAS7 '89 Records, pp829-834,1989

[4] Braz J. Cardoso Filho, Steffen Bernet and Thomas A. Lipo, "A New Control Strategy for the PWM Current Stiff Rectifier/Inverter with Resonant Snubber", Proc. of 28th IEEE Annual Power Electronics Specialists Conference, pp.574-579, June, 1997

[5] S. Abe, T. Ninomiya,Comparison of Active-Clamp and ZVT Techniques Applied to Tapped-Inductor DC-DC Converter with Low Voltage and High Current,Journal of Power Electronics,Vol.2, No.3, pp.199-205,2002.